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THESIS

LIFECYCLE READINESS AND SHIP DEPLOYMENT

by

Andrew G. Shin

June 2013

Thesis Advisor: Gary O. Langford
Second Reader: Michael E. McCauley

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13. ABSTRACT (maximum 200 words)

Historical perspective and previous studies have shown motion sickness has a significant effect on some percentage of ship crews, especially during the early phase of the deployment. This research examined the primary watchstander assignments onboard the Littoral Combat Ship (LCS) platform to ascertain the effects of motion sickness on crew manning, proficiency of work, and indicators of reduced effectiveness in carrying out operations. Potential degradations in performance or in quality of performance due to symptoms of motion sickness were correlated with thirty-six primary watchstander assignments typical of the tasks necessary to carry out the various operational aspects of the LCS. The results were tabulated and formed into a Figure of Merit (FoM). The performance and performance quality were divided into five categories: making decisions, analytical tasks, reading, fine motor, and gross motion, each contributing equally to the FoM considered for manning and operations. By correlating the FoM with the watchstander assignments, the degree of impairment for each watchstander was assessed. Six out of thirty-six watchstations had four different performance or performance qualities affected by motion sickness. The results illustrated the expected and reduced operational effectiveness of watchstander performance qualities based on various sea conditions (calm, moderate, and heavy).

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LIFECYCLE READINESS AND SHIP DEPLOYMENT

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Historical perspective and previous studies have shown motion sickness has a significant effect on some percentage of ship crews, especially during the early phase of the deployment. This research examined the primary watchstander assignments onboard the Littoral Combat Ship (LCS) platform to ascertain the effects of motion sickness on crew manning, proficiency of work, and indicators of reduced effectiveness in carrying out operations. Potential degradations in performance or in quality of performance due to symptoms of motion sickness were correlated with thirty-six primary watchstander assignments typical of the tasks necessary to carry out the various operational aspects of the LCS. The results were tabulated and formed into a Figure of Merit (FoM). The performance and performance quality were divided into five categories: making decisions, analytical tasks, reading, fine motor, and gross motion, each contributing equally to the FoM considered for manning and operations. By correlating the FoM with the watchstander assignments, the degree of impairment for each watchstander was assessed. Six out of thirty-six watchstations had four different performance or performance qualities affected by motion sickness. The results illustrated the expected and reduced operational effectiveness of watchstander performance qualities based on various sea conditions (calm, moderate, and heavy).

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LIST OF ACRONYMS AND ABBREVIATIONS

ABCD	American, British, Canadian and Dutch
DDG	Guided Missile Destroyer
DoD	Department of Defense
FoM	Figure of Merit
FPSO	Floating Production Storage and Offloading
GAO	General Accountability Office
LCS	Littoral Combat Ship
MIF	Motion Induced Fatigue
MII	Motion Induced Interruptions
MSI	Motion Sickness Incidence
NATO	North Atlantic Treaty Organization
NM	Nautical Mile
OOD	Officer of the Deck
OPSIT	Operational Situation
PAQ	Performance Assessment Questionnaire
WBV	Whole-Body Vibration

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EXECUTIVE SUMMARY

Introduction of the U.S. Navy's attempt at reducing manpower is seen through the design and operations of the Littoral Combat Ship (LCS). This strategy of reducing manpower relies heavily on integrating new technology with greater proficiency of the core crew. Consequently, having a lower availability of crew onboard the ships results in fewer crew replacements as back-ups for unpredicted mishaps. A result of the newer ships requiring less crew is that each individual is likely to carry greater responsibility within a given area of the ship. This change from historical manning means that if one individual's performance does not meet the criteria of ship's required level of readiness, the overall operational effectiveness of the ship may be threatened. At the task level, individuals expect and are expected to carry out their duties. Many previous studies have shown that motion sickness has a significant effect on some percentage of the crew especially during the early phase of the deployment (up through the first three days). Motion sickness often limits and reduces the crew's readiness and performance in those first several days. Placing or basing ships within a few days of full-scale operations suggests the topic of motion sickness be considered in light of future potential deployments and operations.

This study examined the effects of motion sickness on crew performance and readiness. Data collected by military medical specialists from the Bangladesh Navy for an 18-month period from August 2007 to January 2009 characterized motion sickness in calm, moderate, and heavy seas. This data was selected to integrate with the performance quality model since there was high compatibility between the work force tasks on the ship. The number of the crew work force ranged from 34 to 91 on twenty-five Bangladesh naval ships. This number of crew was reasonably close to the optimal manning requirement of the LCS. The Bangladesh data showed that among a total of 523 motion sickness affected sailors; 3.82% experienced seasickness in calm sea, 24.28% in moderate sea, and 71.70% in heavy seas. These results were integrated into the performance quality model developed during the thesis research study to determine the expected and reduced operational effectiveness of watchstanders performance and performance quality on various sea conditions. Thirty-six primary watchstanders

assignment were considered to determine the effects of any degradation of performance or performance quality on motion sickness symptoms onboard the LCS. The performance and performance quality was divided into five categories: making decisions, analytical tasks, reading, fine motor and gross motion. The results illustrated the expected and reduced operational effectiveness of watchstander performance qualities significantly increases based on the increased severity of the sea conditions (i.e., calm, moderate, and heavy).

During crisis situations when ships are deployed rapidly, the higher authorities should be cognizant that crew readiness and performance levels are degraded due to motion sickness effects at the early stage of deployment (one to three days). Strategic planning of an operational lifecycle may be affected. It is also noted that depending on the sea condition of the transit, the operational effectiveness of watchstanders aboard ships are gradually degraded with higher severity of sea conditions. This thesis suggests that motion sickness effects on crew performance should be taken into account when reporting operational lifecycle readiness and performance level of the ships.

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I. INTRODUCTION

A. BACKGROUND

In June 2003, a report to Congressional requesters was prepared by the United States General Accountability Office (GAO) after an evaluation of Navy actions that were needed to optimize ship crew size and reduce total ownership costs. GAO determined that the cost of a ship's crew is the single largest cost incurred over the ship's lifecycle. One way to lower personnel costs, and thus the cost of a ship's ownership, is to replace crews with automated technology. The use of fewer people onboard ships will reduce the personnel costs over the ship's lifecycle (GAO, 2003). There is a critical need for a human factors input whenever technology and people interact. The idea of smaller crew sizes onboard ships is feasible only if the systems are reliable and can be maintained and operated with minimum human effort.

The introduction of the Navy's attempt to reduce manpower is seen in the LCS. In the preliminary design document for the LCS interim requirements, the stated critical design parameters were for an objective level for core crew size of 15 with a threshold level of 50. For both core crew and the mission package detachment, the objective and threshold level was 75 (LCS Preliminary Design Interim Requirements Document, 2003). This new strategy of reduced crew size relies heavily on mastering new technology and requires more proficiency of the core crew. As requested by Department of Defense (DoD), GAO was asked to evaluate the Navy's progress toward reducing the crew size in four ships being developed and acquired. The Navy's goal was to cut personnel on the DD(X) by about 60 to 70 percent from that of the previous guided missile destroyer class, DDG-51 (GAO, 2003). Given the contemporary plans to optimize the ship's crew, the crew's effectiveness and skill to perform their required tasks becomes critically important (Stevens & Parsons, 2002). Any degradation in crew performance may be noticeable and damaging to effective operations. The well documented work on motion sickness has not been a significant part of operational planning when ships deploy from the United States and must transit large expanses of water before engaging in full-scale operations.

About 8 million U.S. workers have occupational vibration exposure. Of these, an estimated 6.8 million people are exposed to whole-body vibration (WBV) (Bruce, Bommer & Motritz, 2003; ACGIH2001). As referenced by Paschold & Mayton (2011), WBV comprises the transfer of relative low-frequency environmental vibration ranging from 0.5 to 80 Hz to the human body through a broad contact area (Paschold & Mayton, 2011; ISO, 1997). WBV is widely present on a ship at sea and commonly results in motion sickness (or seasickness). Motion sickness is associated with frequencies below 1 Hz (Mansfield, 2005). Naval personnel are consistently exposed to motion sickness by living and working on ships. Studies that have been completed provide a working knowledge of the multiple issues regarding motion effects on people at sea and how these motions also disturb the balance of crew members, increase the energy expenditure of persons working on board, and often increase the level of fatigue and drowsiness (McCauley, Pierce, and Matsagas, 2007; McCauley, Royal, Wylie, O'Hanlon, & Mackie, 1976; Malek, Maruf, & Hossain, 2009; Stevens & Parsons, 2002; Dobie, 2000).

As ship designs and technology evolve and in particular as crew sizes diminish, greater emphasis should be placed on crew readiness, performance, and quality of performance factors to ensure the safety and efficiency of the crew during operations. Especially in heavy seas, severe ship motions limit the human's ability to operate systems for command, control, and communication. Carrying out necessary navigational tasks, performing routine ship maintenance, and preparing food are likewise challenging in high seas (Dobie, 2000). The physical fatigue associated with ship motions has significant consequences for today's minimally manned ships. "Because of minimally sized crews, any decrease in performance capabilities has major implications for the ship's operational effectiveness" (Stevens & Parsons, 2002). With many sailors exposed to WBV and experiencing motion sickness, the additional knowledge or awareness of this matter may prove useful in planning and executing quick reaction deployments with sailors who have not yet acclimated to the sea environment. In order to maintain 100% war fighting readiness at all times, it is important to consider the degradation of crew readiness and performance during early deployment and to implement mechanisms to preserve them.

B. PROBLEM STATEMENT

As a realistic average during moderate turbulence, about 25% to 30% people become sick to the point of vomiting within the first two to three days of an Atlantic crossing (Chinn, 1963). The Navy Medical Information Management Center showed that between 1980 and 1992, 489,266 new recruits in the Navy were diagnosed with motion sickness, and a further 106,932 revisits were noted (Dobie, 2000). More currently, the information from the naval fleet has pointed to unexpectedly high rates of motion sickness even in deep draft ships, which normally do not experience stimulating motions. This movement led the National Biodynamic Laboratory in New Orleans to observe and explore the effects of motion sickness as it relates directly to a crew's ability to accomplish their tasks and the increased potential for accidents (National Biodynamics Laboratory Website, 2001). The historical perspective of motion sickness concludes that motion sickness is quite prevalent in the naval community. Historical sampling of information also shows that motion sickness is most common during the first two or three days at moderate seas for new as well as experienced sailors. Within the United Kingdom, Pethybridge (1982) found that 10% to 30% of naval crewmembers suffered from seasickness during slight sea conditions and that the incidence rises to 50% to 90% in the heavy conditions (Stevens & Parsons, 2002). Considering the efforts to optimize and minimize the number of a ship's crew (in order to reduce total ownership cost), this thesis investigated the compounding effect of sea sickness that may affect the readiness and performance of sailors especially during the initial phase of the deployment. In crisis situations, will the crews be able to respond effectively and meet the operational readiness?

The modern effort to embrace new technology on newer ships gradually reduces the required crew numbers but at the same time develops a threat to the lifecycle readiness. Lifecycle readiness includes how comfortably the solution of people and technology interact to reflect the lifecycle needs, the broader context in which the technology is considered to have utility in an operational environment, and the flexibility to incorporate all measures and degrees of crew proficiency as they are mapped to the individual tasks of the crew (Langford, 2012). Here, lifecycle can be seen as a structured progression from the build-up to deployment to the end of deployment. The build-up to deployment includes the earliest conceptualization of the need to deploy (or awareness of the opportunity to deploy). The end of deployment includes the last vestiges of utility from deployment (Langford, 2012). Lifecycle success, i.e., mission success, delivers the lowest losses to the stakeholders of the deployment. These stakeholders include the planners, the ship's crew, the support people, and the corporeal aspects of the ship and the consequences of the deployment. Lifecycle is enacted through stages where each stage is highly organized with checks and balances to reduce the risk of loss. Such loss might be construed as the degradation of crew performance due to motion sickness in carrying out a task (Langford, 2012).

In critical military tasks, severe motion sickness effects on ship's crew would hamper mission effectiveness (Malek, Maruf, & Hossain, 2009). The reduced availability of crew onboard the ships means fewer replacements are available for back-up at any unpredicted mishaps. As the newer ships require less crew, each individual is likely to carry more responsibility on certain areas of the ship. This means that if one individual's performance does not meet the criteria of ship's required level of readiness, this reduced performance may threaten the overall operational effectiveness of the ship. Many of previous studies have shown that motion sickness has a significant effect on some percentage of the crew especially during the early phase of the deployment (up to the first three days) which often limits and reduces the crew's readiness and performance. The problem is that without proper awareness of motion sickness effects on crew readiness and performance, risks in crew safety and ships' operational efficiency may exist on unexpected or rapid deployment. A general knowledge and discussion to mitigate or prevent motion sickness may increase the overall operational readiness of any forward deployed forces.

C. SCOPE OF THE THESIS

Motion sickness is associated with a variety of motion environments, such as on ships, in aircraft, in vehicles, in zero gravity environments (space), and even in elevators (Stevens & Parsons, 2002). The symptoms and physiological responses are consistent for most instances of motion sickness; however, the purpose of the study is to examine the motion sickness associated in the sea environment. Seasickness is the most common form of motion sickness and has a profoundly adverse effect on human performance (Dobie, 2000). The scope of this research is to examine the effects of motion sickness (commonly referred as sea sickness) on crew members of military ships during the initial phase of the deployment (up to the first three days). The research considered dizziness, fatigue, nausea, and vomiting as the common symptoms of motion sickness. There are many other factors that affect crew readiness and performance during the early stage of a deployment. The inefficiencies in performance may develop from lack of training, different personal aptitude, and individual's mental or physical conditions. The magnitude of the effects of motion sickness is also different depending on type of ship. Large ships, such as carriers or amphibious landing ships are designed and expected to present the crew with less motion than smaller ships. The research focused on gaining knowledge and awareness of motion sickness effects on small size ship – equivalent to the size of a destroyer or smaller in displacement, such as the LCS. It is important to understand that different sea state conditions upon deployment are another variable that may affect the severity of motion sickness and their impact on crew readiness and performance. The results of this research will allow readers to understand the reduced and expected efficiency of crew readiness and performance on various levels of sea state, especially during the early phase of a deployment.

D. RESEARCH QUESTIONS

- How does motion sickness affect crew readiness/performance during the first 5 days of an initial deployment period? What are the effects of motion sickness during the initial phase of the deployment?
- How effective are current methods and solutions used by the Navy to neutralize motion sickness?
- Are there any mitigations and studies to improve crew readiness and efficiency before deployment?
- What are some solutions to ensure efficient crew readiness during initial deployment?
- Will the sailors be in a high war fighting readiness during unexpected deployment to an area of interest that is close by the deployment point?

- How is crew readiness different between initial deployment and subsequent time at sea?
- What is the relationship between crew readiness/performance and number of days at sea?

E. BENENFIT OF STUDY

The primary benefit of this study is recognizing and expanding the knowledge of motion sickness effects on human performance and readiness. Especially during the first two to three days of deployment, it is historically proven that motion sickness can cause significant impact to ship's readiness. In a catastrophe situation, ships may be required to be on station at a certain area of interest at short notice. This knowledge can lead to information for commanders, identifying operational limits and risks associated with the ships undergoing the initial phase of deployment. One potential benefit of this study is to enhance decision making of the Navy in optimizing manpower on future ships. Another benefit of this study is to demonstrate the possibility of human performance and readiness (human factors) integration into operational effectiveness.

F. METHODOLOGY

The methodology for this study consisted of four parts. First, perform a comprehensive research of available data and resources relevant to the effects of motion sickness on crew at sea. Second, develop a working model of the determinants of motion sickness as they correlate to symptoms of motion sickness (as observed through the expected number of crew affected by motion sickness with a performance quality model). Third, develop a model that synthesizes the effects of motion sickness on operational effectiveness of the crew. Fourth, validate the model and convert the model into descriptive text.

II. LITERATURE REVIEW

A. INTRODUCTION

The effects of motion sickness and its relationship to human readiness and performance is the primary focus of this literature review. In order to understand the impact of motion sickness on human readiness and performance, one must understand the basic theory and mechanisms of motion sickness. The study of motion sickness is analyzed with various historical studies and experiments performed over the past 50 years. The purpose of this literature review is to illustrate and verify that motion sickness influences human readiness and performance onboard ships.

The literature review is divided into three sections. The first section consists of an overview of motions sickness, its definitions and mechanisms. The second section consists of an overview on symptoms and effects of motion sickness on humans. The third section discusses historical data and experimental data that indicate effects of motion sickness on human readiness and performance.

B. MOTION SICKNESS

1. Definition

As universally defined, motion sickness is a broad term for the discomfort, dizziness, nausea, and vomiting that people experience when their sense of balance and stability is disturbed by a constant motion. Riding in a car, aboard a ship, or riding on a swing all cause irregular and abnormal motions to the vestibular system and visual stimulation that often leads to discomfort (Stevens & Parsons, 2002). Motion sickness is most commonly found at frequencies lower than 1 Hz, which is slightly different from whole-body vibration which often occurs at frequencies higher than 1 Hz (Mansfield, 2005). The entire population experiences motion sickness at some point in their lives; with a rare 5% hardly being affected and 5% being severely affected (Wertheim, 1998).

2. Mechanism

The mechanism of control for an individual's ability to stand, maintain balance, and perform the process and function of moving is to coordinate the inputs from the eyes, ears, and sense of touch with that of an integrated neural action to stimulate muscles for motion. Disruption of syncopated movement can be caused by the vestibular apparatus (balance mechanism) in the inner ear. The composition of the vestibular apparatus is primarily capillaceous lined cannels and sacs, both filled with fluid. Bending of this fine hair-like liner stimulates a neural response that is transmitted to the brain. The information contained in this transmission (based on the bending of hair-like structures) includes the orientation of the head relative to the body. This sensory response captures the information from the perspective of the head relative to the body. If sensory information is available from the optical sensors (i.e., the eye) the orientation of the body relative to the ground is compared with the information from the inner ear (referred to as the cerebellar-vestibular system). Likewise, the sense of touch (i.e., tactile response) signals the brain about the body contacts with objects. Since the optical sensors are a primary source of information for perspective in maintaining motor control over bodily motions, the integrated response of the brain to information from the inner ear and the eye is a dominant determinate of balance. Additionally, the proprioceptive system (i.e., the physiological response of body parts to stimuli) provides information on the relative position of muscles. When the confluence of information is interoperable, the perspective of balance and motion is coordinated. However, when the information is integrated, but diachronic, the sense of balance is lost, dizziness and disorientation occurs, and the afflicted individual may experience malaise and in extreme cases, vomit. It suffices to state, the cerebellar-vestibular system coordinates balance, muscle movements, and various cognitive processes and functions.

In addition to balance and coordination, concentration is affected. The inner-ear filters and regulates auditory data. Without sufficient ability to concentrate, an afflicted individual may have short lapses of cognitive functioning – the greater the affliction, the greater the lapse of cognitive functioning. Reading is affected due to lapses in cognitive functioning, as are coordinated movements of the eye, reasoning and interpretation, and fine-motor skills, e.g., hand-eye coordination. A general cognitive “fog” typifies the malaise caused by motion sickness.

3. Origin

An experiment was conducted in the 1960s wherein researchers compared twenty participants with normal hearing to ten participants who were labyrinthine-defective (LD). Labyrinthine-defective refers to a defective vestibular system. The result of the experiment showed that the L-D participants had little to no signs of motion sickness, while participants with normal hearing showed significant signs of motion sickness (Kennedy, Graybiel, McDonough & Beckwith, 1968). The vestibular system’s role in motion sickness was learned when it was discovered that people without working vestibular systems, either due to disease or genetic imperfection, could not experience motion sickness (Benson, 1999). Stevens & Parsons (2002) also stated that the vestibular system or the inner ear of human body is the primary instrument responsible for feelings of nausea and disorder. The vestibular system detects motion of the head and body relative to the earth and creates reflexive motor activity that improves motion control while motion is in progress (Guedry, 1991b).

4. Theory and Causes

Many theories exist to explain why and how motion sickness occurs; however, the most broadly accepted theory is known by numerous names: conflict mismatch theory, sensory rearrangement theory (Reason & Brand, 1975), and neural mismatch theory (Benson, 1999). These theories all describe the cause of motion sickness via the same scheme: that the vestibular system within the inner ear provides the brain with information about self-motion that does not match the sensations of motion generated by visual or kinaesthetic (proprioceptive systems), or what is expected from previous experience (Wertheim, 1998a). The prime example of this phenomenon is explained by Stevens & Parsons (2002) using a person inside a ship cabin at sea. Stevens & Parsons states that “While the vestibular system is registering vertical and angular accelerations, the visual system does not register any motion at all and thus a conflict of the senses occurs. An understanding of this theory immediately provides explanation for a well-known remedy for seasickness: by providing the visual senses with a stable horizon as seen from a weather deck or through a large porthole, the severity and incidence of motion sickness is reduced" (Stevens & Parsons, 2002).

5. Sensory Mismatch

Summarizing the sensory mismatch stated by Stevens & Parsons (2002) and Griffin (1991). The sensory mismatch occurs due to either Type 1 or Type 2 intersensory conflict or an intrasensory conflict. Intersensory conflict refers to incompatible signals from two primary sensory systems, the eyes and the vestibular system. Type 1 intersensory conflict occurs when both the eyes and the vestibular system detect motion, but the two systems do not agree with expectation based on previous experiences. Type 2 intersensory conflict occurs when either one of the system processes an input without the input of the other system. Intrasensory conflict occurs when the inner ear and the optical inputs are at inconsistency with one another. In other words, the linear acceleration transducers (otoliths) are registering motion of a different type than the angular acceleration transducers (semicircular canals). Type 1 intrasensory conflict occurs when both the otoliths and semicircular canals detect motion, but of an incompatible kind and the two systems do not accord with expectation. Type 2 intrasensory conflict occurs when either one of the signals are processed from one but not the other (Stevens & Parsons, 2002; Griffin, 1991a). The information on the types of conflict is summarized in Table 1.

Table 1. Types and categories of sensory conflict (From Griffin, 1991a).

Type of Conflict	Category of Conflict	
	Intersensory (Visual – Vestibular)	**Intrasensory (Canal – Otolith)**
Type I	Visual and vestibular systems simultaneously signal different (i.e. contradictory or uncorrelated) information.	Canals and otoliths simultaneously signal different (i.e. contradictory or uncorrelated) information.
Type IIa	Visual system signals in the absence of an expected vestibular signal.	Canals signal in the absence of an expected otolith signal.
Type IIb	Vestibular system signals in the absence of an expected visual signal.	Otoliths signal in the absence of an expected canal signal.

As referenced by Stevens & Parson (2002), in 1990, Griffin developed a conceptual model of factors possibly involved in connection of motion sickness. Factors include drugs, alcohol, experience, mental activity, non-motion environment, posture, age, and gender. Figure 1 shows the conceptual model.

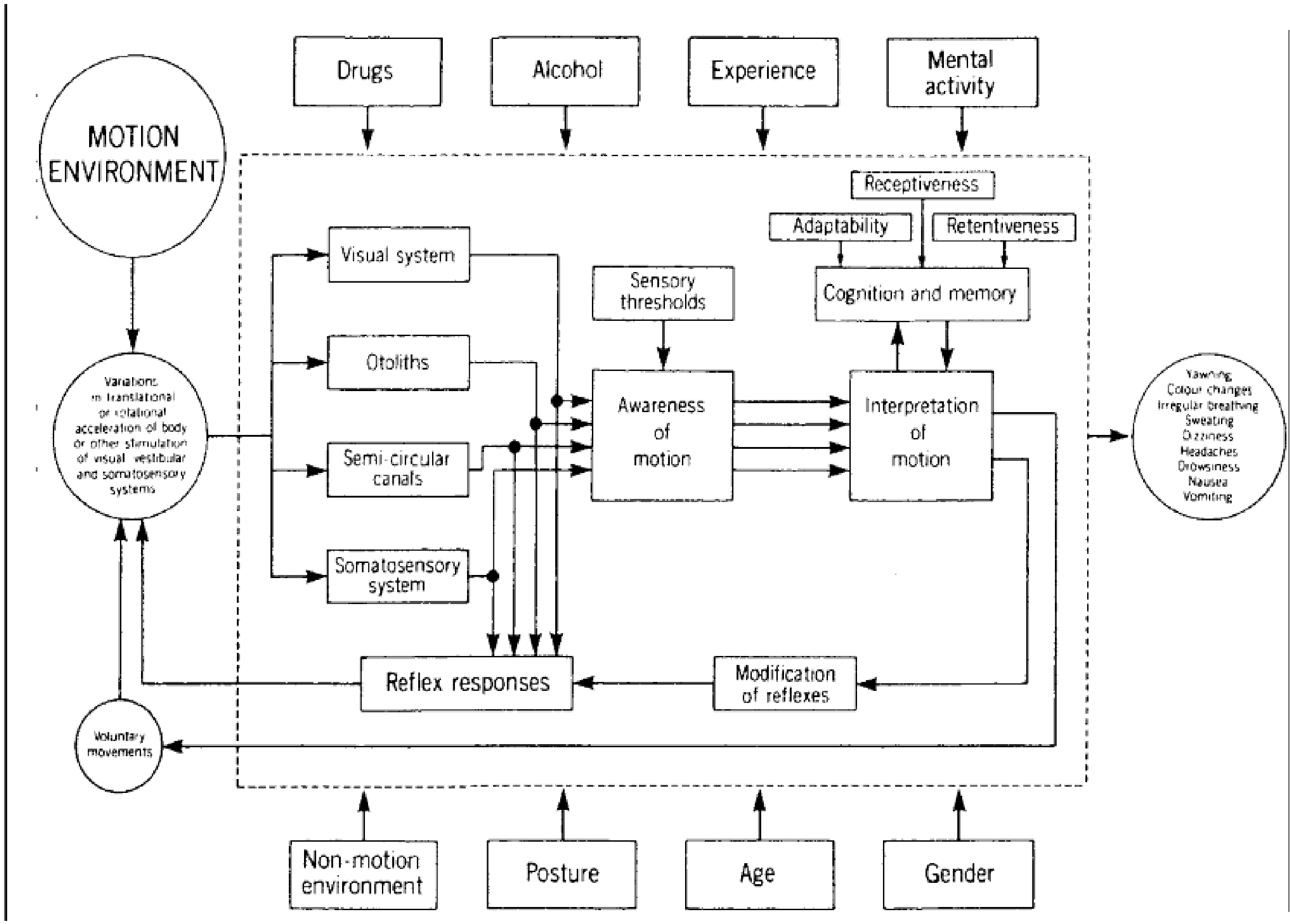

Figure 1. Conceptual model of factors possibly involved in connection with motion sickness (From Griffin, 1990)

C. EFFECTS OF MOTION SICKNESS

1. Susceptibility

The effects of motion sickness are variable depending on the experience, personality, gender, age, and adaptability of the person. A person's personality and past motion experiences affect and influence their future outlook towards attempts at conquering their symptoms and placing themselves in provoking motion environments (Guedry, 1991a). As referenced by Stevens & Parsons (2002), females appear to experience motion sickness more often than males by a ratio of 1.7 to 1 (Benson, 1999; Lawther & Griffin, 1985). In a large study done in India, data collection on susceptibility to motion sickness on 535 individuals, showed the prevalence of motion sickness was greater in females being more susceptible (27%) than males (16.8%) (Sharma, 1997). Additional elements that influence an individual's susceptibility to motion sickness include the type, frequency, duration, and intensity of the motions faced (Stevens & Parsons, 2002).

Lab experiments aboard aircrafts and ships have discovered that crews who maintain and sustain their mental concentration on a particular task are less likely to experience motion sickness than those who are not as engaged (Stevens & Parsons, 2002). According to Benson (1999), relaxation and time for introspection allow for more accurate reporting and discrimination of bodily sensations that lead to motion sickness. However, once the onset of minor symptoms of motion sickness is noticed, only removing the confounding information reduces the symptoms. Therefore, it is important to recognize the onset of symptoms and deal immediately with that situation by eliminating the differences in motion between the head and the body, the head-body and the surrounding structures, and resting with eyes closed. According to Stevens & Parson (2002) there are a number of temporary predisposing factors that influence one's exposure to motion sickness: temporary abdominal upset, ear swelling, alcohol drinking, and headache. These factors increase one's potential for motion sickness, while anxiety or panic associated with motion sickness may heighten one's sense of stimulation leading to increased susceptibility (Stevens & Parson, 2002; Guedry, 1991a).

2. Adaptation

The natural cure for preventing or curing motion sickness is adaptation (Stevens & Parsons, 2002). Motion sickness may be elicited in as little as a seconds or minutes in the case of some laboratory, while it takes considerably longer in response to ship motions (Griffin, 1990). Adaptation process takes various times depending on the individual's rate of adaptation and it is inevitable to experience motion sickness especially during early phase of the deployment. Nevertheless, minimum populations of the crew are unaffected due to natural immunization to motion sickness. Figure 2 shows the form of the variation of motion sickness incidence (MSI) over time for a population exposed to ship motions, where MSI is defined as the percentage of people who vomit. It is safe to assume that larger percentage of population are likely to experience other signs of motion sickness since the figure only indicates people who vomit. However, the figure proves that typical adaptation process occurs and most population experience motion sickness especially during first three days at sea. Hill (1936) estimated that over 90% of inexperienced passengers become seasick in very rough conditions and some 25% to 30% became seasick during the first two or three days in moderate seas.

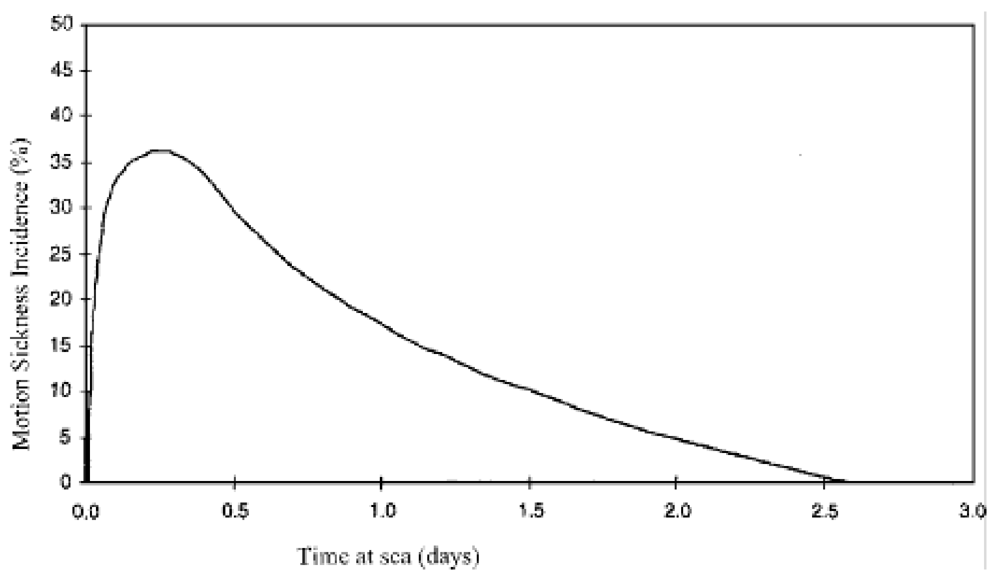

Figure 2. Motion sickness incidence (MSI) over time for a population exposed to ship motions where MSI is the percentage of people who vomit (From Crossland, 1998)

3. Symptoms

The symptoms of seasickness are well known and most often ignored until the individual gradually adapts to the condition (Griffin, 1991a). Money (1970) described symptoms of motion sickness as a general feeling of illness, upper stomach sensations, sleepiness, apathy, and headache are the most frequently informed symptoms of motion sickness. Other than nausea, these symptoms are considered reliable indications (Money, 1970). Repeatedly, people are not conscious of the motion as the foundation of their discomfort and will attribute it to other reasons such as food, odors, temperature, or clothing (Griffin, 1991a). According to Benson (1999), discomfort, or stomach awareness, is usually the first symptom. This self-reporting is followed by deterioration of well-being and nausea of increasing intensity. Sweating also occurs, even when temperatures are already excessive (Stevens & Parson 2002; Benson, 1999). Stevens & Parsons (2002) reported that "a rapid exacerbation of symptoms known as the avalanche phenomenon follows which includes: increased salivation, bodily warmth, and light-headedness" (Stevens & Parsons, 2002). Griffin (1990) also reported other typical signs as yawning, irregularities in inhalation, sleepiness, headaches, and feelings of indifference to one's fortune. These typical signs are indicative of a lack of oxygen due to the body's distinctive reflexive response to quiet down the sensory inputs to settle the cognitive patterns, i.e., reestablish interoperability. Finally, the conclusion of an avalanche of symptoms usually results in vomiting. According to Stevens & Parsons (2002) in highly susceptible people, or those with a low capacity for adapting to the motion, vomiting may continue for several days. The consequence of repetitive vomiting may result in anorexia, depression, apathy and incapacity to carry out duties. Additionally, a self-security psychosis may take over and the afflicted individual may insistently look out for their own safety. Stevens & Parsons (2002) also added that "these effects can then be compounded by resulting dehydration and electrolyte imbalances due to repeated vomiting". Numerous individuals suffer the misery of motion sickness without vomiting, and their diminished motivation and apathy makes for safety concerns not only for themselves but for others around them, and depending on the nature of work for which they are responsible, for the very ship itself (Stevens & Parsons, 2002).

Additionally, crew members otherwise invulnerable to motion sickness often catch themselves loaded with extra tasks and responsibilities to ensure proper operation of the ship. Symptoms of motion sickness degrade the performance of an individual and reduce the desire to succeed or survive (Griffin, 1990). Also, sleep deprivation magnifies the occurrence of motion sickness because it interferes with the cerebellar-vestibular system processes of habituation. In the oceanic environment, lack of sleep is often a compounded problem since the sleeping conditions aboard a vessel are often not favorable to peaceful sleep (Dowd, 1974).

4. Performance Impact

The human operator working on a moving platform is susceptible to degraded performance. There are the purely physical limitations imposed by heavy seas on both gross and fine motor skills involving whole-body motion. These skills include standing, walking, and carrying out operational and maintenance tasks that include major physical movement (in order to carry out mechanical operations). These physical limitations include motion induced interruptions (MII) which occur when local motions cause a person to lose balance or slip, thereby interrupting whatever task is being performed. Fine motor skills include delicate adjustment of controls, computer operations, and certain maintenance tasks involving electronic boards and components. Physical operations carried out on a moving platform also induce fatigue and degradation of mental effort leading to an overall decrement of human performance and increased potential for injury. Birren (1949) proposes that peak efficiency is likely to be unaffected most forms of sickness. However, maintenance efficiency, or their ability to conduct daily work, may suffer severe decrements as a result of motion sickness.

Ship motions influence a crew’s ability to conduct their prescribed duties in a number of ways. Wertheim (1998) differentiated between general and specific effects of motion. First, general effects of motion sickness refer to reduced performance on a task that ought to be a motivational nature, an energetic nature, or of a biomechanical nature in a sea environment (Wertheim 1998a).

a. General Effects on Crew

Motivational – Stevens & Parsons (2002) defines it as "the sickness and nausea as well as the drowsiness and apathy associated with seasickness significantly reduce one's motivation to conduct their required tasks and duties".

Energetics – The extra effort exerted to maintain and sustain one's balance on a moving platform which, induces fatigue and degrades mental effort, this results to decreased human performance (Stevens & Parsons, 2002).

Biomechanical – The potential for losing one's balance on a moving platform, which often leads to a casualty, is always present at sea environment and dramatically increases with heightened sea states (Stevens & Parsons, 2002).

b. Specific Effects on Crew

The specific effects of a motion environment on human performance refer to interference with specific human abilities or skills. These effects are categorized into complex tasks, cognitive tasks, motor tasks, and perceptual tasks (Stevens & Parsons, 2002).

Complex tasks – Responsibilities carried out on the bridge or navigation centers of ships. These tasks are complicated, have multiple or conflicting problems, and require many sophisticated skills to perform (Stevens & Parsons, 2002).

Cognitive tasks – Responsibilities that require large quantity of mental work. Tasks include tracking a "blip" on radar, writing a sentence, listening to directions, or adding a set of numbers to plot a course, require human cognitive and psychomotor abilities such as mathematical reasoning, verbal comprehension, and verbal reasoning and visual perception (Stevens & Parsons, 2002).

Motor tasks – Motor skills include such tasks as manual tracking or fast "button" or keyboard "press" reactions. These skills will vary with a number of factors in a moving environment (Stevens & Parsons, 2002).

Perceptual tasks – Responsibilities requiring visual or auditory detection of various signals (Stevens & Parsons, 2002).

D. MOTION SICKNESS INCIDENCES

The incidence of motion sickness at sea varies from less than 1% to almost 100% depending on the criterion for its presence, the vessel, the sea conditions, and various other factors (Chinn, 1963; Tyler, 1949). Attias et al (1987) reported that aboard a 300 ton vessel in Sea States 2 and 3, 53% of those not receiving sea sickness medications were sick on the first two days and 23% were sick on the third day. The incidence of seasickness among surviving aircrew in life rafts on the ocean is reported to be 60%, and under these circumstances the sickness has “probably contributed, directly or indirectly, to many death” (Llano, 1955) by hastening dehydration. Table 2 is a Beaufort scale illustrating the sea state number with the corresponding wind speed, wave height, and the description of sea conditions.

Table 2. Sea states in Beaufort scale (From Seabreeze.com)

Beaufort Number	Description	Wind Speed	Wave Height		Sea Conditions
		Knots	Meters	Feet	
0	Calm	< 1	0	0	Flat.
1	Light air	1 - 2	0 - 0.2	0 - 1	Ripples without crests.
2	Light breeze	3 - 6	0.2 - 0.5	1 - 2	Small wavelets. Crests of glassy appearance, not breaking
3	Gentle breeze	7 - 10	0.5 - 1	2 - 3.5	Large wavelets. Crests begin to break; scattered whitecaps
4	Moderate breeze	11 - 15	1 - 2	3.5 - 6	Small waves with breaking crests. Fairly frequent white horses.
5	Fresh breeze	16 - 20	2 - 3	6 - 9	Moderate waves of some length. Many white horses. Small amounts of spray.
6	Strong breeze	21 - 26	3 - 4	9 - 13	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.
7	High wind, Moderate gale, Near gale	27 - 33	4 - 5.5	13 - 19	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.
8	Gale, Fresh gale	34 - 40	5.5 - 7.5	18 - 25	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.

Continued on next page

From the previous page

9	Strong gale	41 - 47	7 - 10	23 - 32	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.
10	Storm, Whole gale	48 - 55	9 - 12.5	29 - 41	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.
11	Violent storm	56 - 63	11.5 - 16	37 - 52	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.
12	Hurricane	= 64	= 14	= 46	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.

In military flight training, approximately 10% to 18% of student pilots suffer from motion sickness at some time during the early stages of training, and motion sickness occurred during 2.46% of a series of training flights surveyed. On the 1st flight 5.7% of the student pilots were sick, and on the 10th flight only 1.1% was sick. At some time during their training 66% of student navigators suffer from motion sickness and motion sickness occurred during 15.6% of the navigation training flights studied (Money 1970). Trumbull et al (1960) found the incidence of vomiting reported on military transport ships traveling across the Atlantic to vary from 8.5% to 22.1% on three crossings.

Bruner (1955) observed from a questionnaire survey of 699 men aboard destroyers involved in escort duty in the U.S. Navy that 39% were never sick, 39% were occasionally sick, 10% were often sick, and 13% were almost always sick. Empirical data from Rodahl & Vokac (1979) also indicate that ship motions are accountable for added energy expenditure of the crew. During coastal fishing it was found that when steering the boat, the skipper worked at 37% of maximal aerobic power considerably higher than when standing still ashore. This additional effort was attributed to the need to counterbalance the body in response to the motions. Finally, Astrand et al. (1973) reported that during coastal fishing, heart rate and oxygen consumption were markedly higher in conditions of rough weather than during calm weather.

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III. SYSTEMS ENGINEERING ANALYSIS

A. OPERATIONAL SITUATION (OPSIT)

For the purposes of this thesis, the following notional scenario was examined.

In many consecutive years, North Korea has announced that it will no longer abide by the armistice. Most recently in 2013, a North Korea crisis escalated the tensions between North Korea and South Korea, the United States, and Japan. The crisis directly threatened South Korean and the United States due to possible imminent attacks of the nuclear weapons (Yonhap, 2013). After several months of tension, the United States faced a major conflict with North Korean Navy. During the U.S holiday stand-down period, usually from mid-December through mid-January, a South Korean naval vessel patrolling along the 38th parallel line was hit by a surface-to-surface missile. The South Korean President requested immediate assistance and support from the United States Naval Forces. No ships were available in the theater because of the holiday stand-down period. However, several ships were stationed in their homeport, Yokosuka Naval Base, and were going through short maintenance availability. Within short notice, USS Curtis Wilbur (DDG-54), USS Fitzgerald (DDG-62), and USS Lassen (DDG-82) were sent to the area of interest. Many ships were deployed with reduced number of crew members due to some members being unable to return in time from their holiday leave. Many mishaps and emergencies were reported from the deployed ships. Each ship's Captain realized that the readiness of the ship was lower than expected and the performances of the crew were reduced.

The ship will operate in the open ocean transit from the North Pacific Ocean of Yokosuka Naval Base to East China Sea near Incheon. Depending on the time and weather of the day, the sea state ranged from the Beaufort scale of 0 to 7. While it was policy to always prepare for the worst case scenario, the under manning coupled with the likelihood of the ships going through waters of sea state 6, almost ensured a difficult situational readiness. Figure 3 shows the data from Oceanweather Inc accessed on June 7, 2013 (http://www.oceanweather.com/data/).The transit route, from Yokosuka Naval Base to West Ocean front Incheon, was likely to experience 0.5 to 3.5 meters of wave heights. Comparing this data with Douglas Sea Scale, it is likely that ships are going to face moderate to rough seas during the transit. It was also important to consider that transit speed of the ships will greatly affect the motion of the ship.

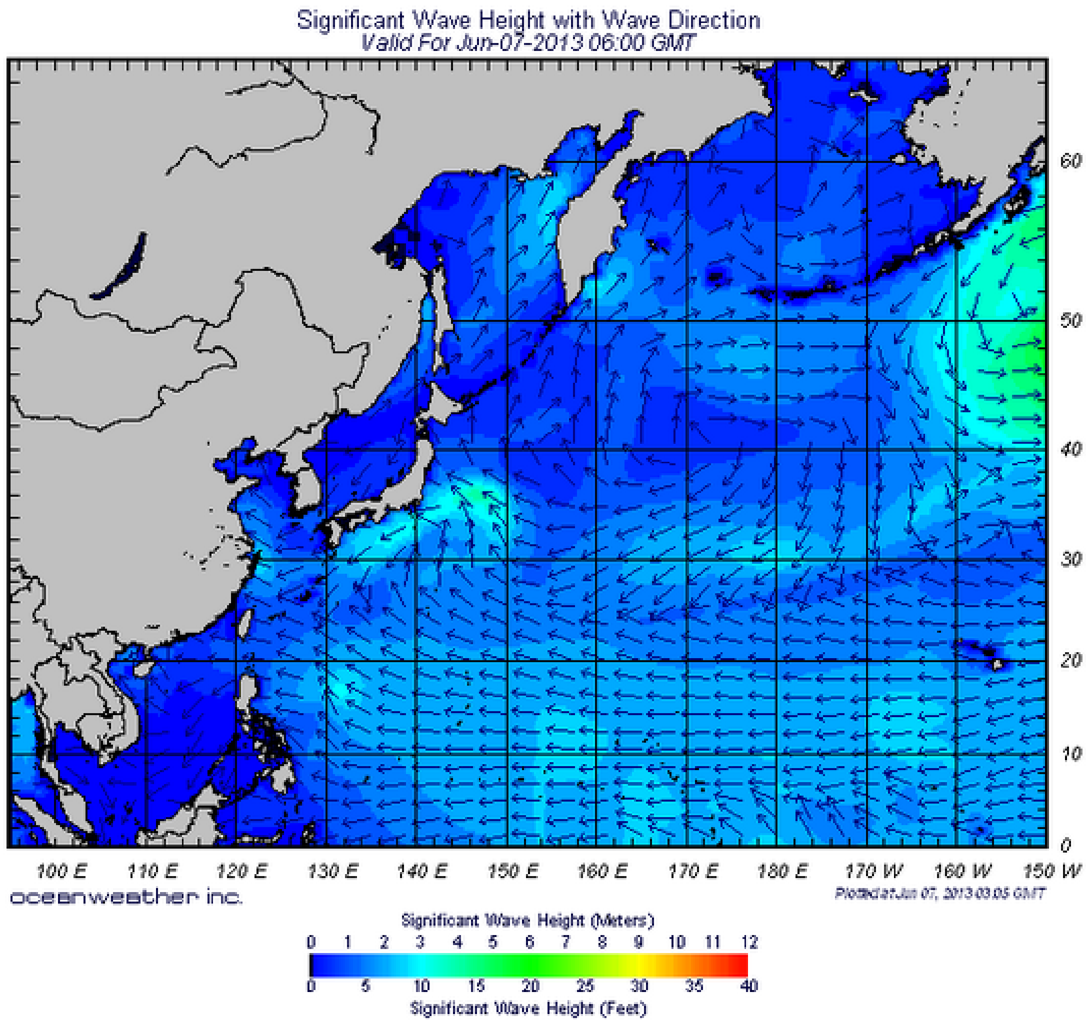

Figure 3.   North Pacific Western region marine data (From Oceanweater Inc.)

The main threat for this OPSIT is that the United States Navy's operational readiness and performance of the crew at the time of arrival is expected to be degraded. The arrival is within three days of departure and the crews had been in port for an extended period of time. The North Korean Navy planned and prepared for this attack to coincide with U.S. ship maintenance availabilities. The North Korean Navy was at the highest war fighting efficiency. A large portion of the United States Navy crews were degraded in readiness and performance, not because of lack of training, but due to the quick transit through the moderate and heavy seas resulting in motion sickness. Despite the fact that the United States Navy had better operating ships and advance weapons, in order to win the battle against the North Koreans, the readiness and performance of the crew was going to play a key role.

B. STAKEHOLDER ANALYSIS

1. United States Navy Fleets

The core mission of the Navy is to maintain, train, and equip combat-ready naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas. Currently, there are six major active United States Navy fleets across the world. However, United States Tenth Fleet was excluded from the research OPSIT and stakeholder analysis because the command is not relevant to experiencing motion sickness in a sea environment. United States Tenth Fleet is responsible for the Navy's cyber warfare programs.

The United States Third Fleet is located in San Diego, California. Third Fleet's area of responsibility includes approximately fifty million square miles of the eastern and northern Pacific Ocean areas including the Bering Sea, Alaska, the Aleutian Islands and a sector of the Arctic. Major oil and trade sea lines of communication within the area are critically important to the economic health of the United States and many other nations throughout the Pacific Rim region. The primary mission of the Third Fleet is one of conflict deterrence, but in the event of general war it would conduct prompt and sustained combat operations at sea to carry out the United States strategy in the theater (John, 2011).

United States Fourth Fleet is located in Mayport, Florida. Fourth Fleet's area of responsibility includes the Caribbean, and Atlantic and Pacific Oceans around Central and South America. The primary mission is to support full spectrum military operations by directing U.S. naval forces operating in the Caribbean, Central and South American regions and interact with partner nation navies within the maritime environment. Various operations include counter-illicit trafficking, Theater Security Cooperation, military-to-military interaction and bilateral and multinational training (U.S. Navy, 2008).

United States Fifth Fleet is located in Manama, Bahrain. The area of responsibility covered by Fifth Fleet is approximately 2.5 million square miles of water space. The area includes the Persian Gulf, Read Sea, Arabian Sea, Gulf of Oman, and parts of the Indian Ocean. Some of the main area of interest includes the choke points at the Strait of Hormuz, the Suez Canal, and the Strait of Bab al Mandeb. The primary mission is to conduct persistent maritime operations to forward United States interests, deter and counter disruptive countries, defeat violent extremism and strengthen partner nations' maritime capabilities in order to promote a secure maritime environment in the area of responsibility (U.S. Navy, 2013).

United States Sixth Fleet is located in Naples, Italy. The area of responsibility for Sixth Fleet includes water and air space over the Mediterranean Sea, adjacent inland areas, and the Black Sea. The primary mission is to execute maritime power projection operations during peace or crisis in support of North Atlantic Treaty Organization (NATO) objectives and to advance security and stability in Europe and Africa (John, 2011).

United States Seventh Fleet is located in Yokosuka, Japan. Seventh Fleet's area of responsibility includes more than 48 million square miles from the Kuril Islands in the north to the Antarctic in the south, and from the International Date Line to the 68th meridian east, which runs down from the India-Pakistan border. The area includes 35 maritime countries and the world's five largest foreign armed forces, People's Republic of China, Russia, India, North Korea, and Republic of Korea. The primary mission is to defend the United States against attack through the western Pacific and Indian Oceans. Also, the Seventh Fleet maintains the security of the Pacific command and supports the operations of adjacent allied and national commanders (John, 2011).

For an overview illustration, Figure 4 shows the map of the world with designated areas of responsibility for each of the U.S. naval fleets. Other naval bases around the globe are also included in the stakeholder analysis. These include the naval base in

Norfolk, Virginia; Little Creek, Virginia; Pearl Harbor, Hawaii; Everett, Washington; Sasebo, Japan and lastly Changi, Singapore. The naval base at Guam will be excluded since only submarines are located there. The list of United States Navy ships with their homeports are provided in the Appendix B.

In addition to these U.S. stakeholders, countries involved or potentially involved in the conflict are stakeholders, including the Republic of Korea, Japan, North Korea, and the People's Republic of China.

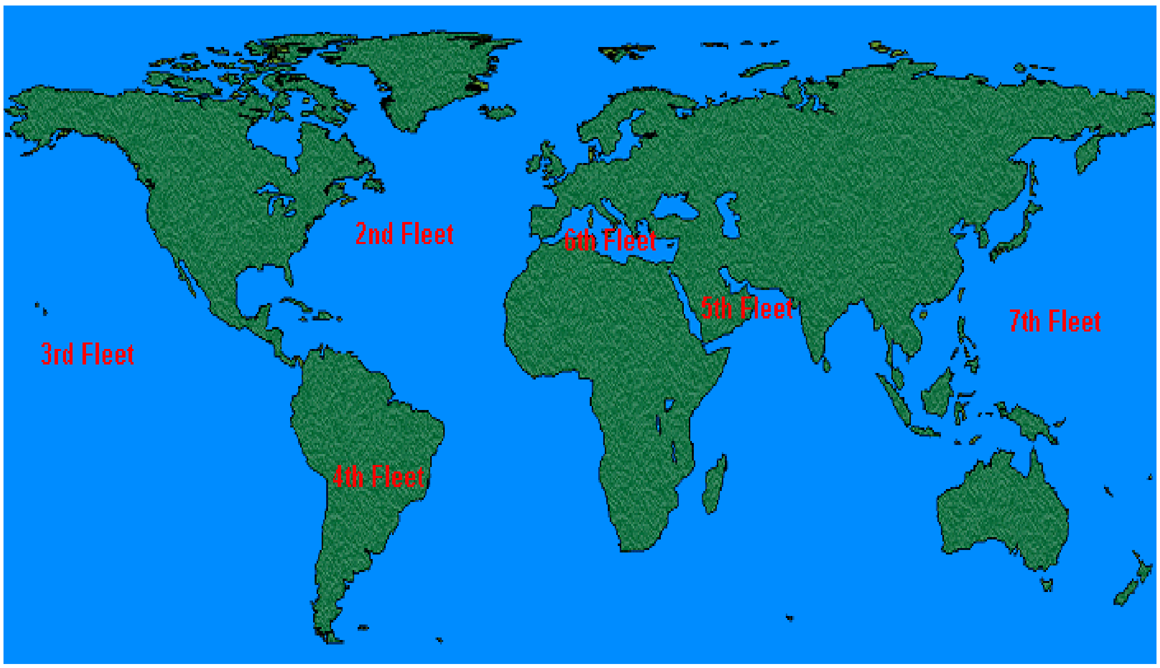

Figure 4. Area of responsibility of United States naval fleets (From Navysite.de)

2. Motion Sickness Involved Distance

From the literature review of Wertheim (1998a): *Working in a moving environment*; Griffin (1990): *Motion sickness;* and Crossland (1998): *Research on motion sickness of human at sea environment*, it is safe to assume that sea sickness is most affected during first three days at sea. As discussed in the operational situation, it is highly probable that the crew's readiness and performance will be reduced by the effects of motion sickness during this early lifecycle of deployment. It is expected that the crew will be less susceptible as the days at sea increase and begin adapting to the sea environment. However, in crisis situations when time of accommodation to motion is short, the crew must fight through their mental and physical discomfort to meet their operational readiness requirements.

Stakeholder analysis is performed to identify which of the current naval fleets are likely to experience the expected and reduced crew readiness and performance upon rapid deployment to an area of interest. First the calculation of possible travel distance based on speed and time was populated in Appendix C. The travel speed was then separated into three categories. The Slow category represents the ship's average traveling speed over a day from 1 to 10 knots, which allows the ship to travel between 24 nautical miles (NM) up to 240NM. The same concept calculus was applied to categorize the moderate and fast speeds of the ship's average traveling mode. Table 3 shows the three categories travel speed with the maximum travel distance. The critical stakeholders are then identified by estimating the distance between geographical location of the Naval Fleet base to the possible area of interest or imminent threat zone using routes over open waters. If the distance between the naval bases and area of interest lies within any of the possible traveling distance based on various travel speeds, the Naval Fleet is determined as critical stakeholder and should be aware of motion sickness affecting performance and readiness of the crew during to the first three days after deployment.

Table 3. Maximum distance traveled based on travel category

		Travel Distance Based on # of days		
Speed Category	Range of Travel Speed	1	2	3
Slow	1 - 10 kts	24nm - 240nm	48nm - 480nm	72nm - 720nm
Moderate	10 - 20 kts	240nm - 480nm	480nm - 960nm	720nm - 1440nm
Fast	20 - 30 kts	480nm - 720nm	960nm - 1440nm	1440nm - 2160nm

C. MEASUREMENT OF PERFORMANCE

In this section of the study, Langford (2012) defines the measurement of performance. A performance measure is a numeric description of the model and the results of the model. Performance measures are based on data and describe whether the model is achieving its objectives. Measures of effectiveness relate the utility of the model to the overall goal of the model and the results of the model performing as it is intended for the particular analyses. Technically, a performance measure is a quantifiable expression of the amount, cost, or result of activities that indicate how much or how many. Quantifiable means the description can be counted more than once, or measured using numbers. The quality of the performance measure is directly related to the variability in those counts or numbers. From the developer's perspective, the model should produce a result in certain amount of time (a measure of model performance). Good performance measures are relevant, understandable, timely, comparable, reliable, feasible, useful, significant, and cost justifiable. The most efficacious performance measures are those that relate actions and results. The basis for efficacious performance should be a theory of causality, a logic model (approach), and a method. Potential measures of performance derive from relating the purpose of the (model) to what is accomplished according to the intended usefulness of the output of the model.

Specifically, the functions carried out by the ship's crew for each of their assigned duties are measured by the performance of each individual and the quality of the individual's work. In effect, the individual's susceptibility to sea sickness is related to the performance of the duties assigned to that individual. Each job can be classified as involving various human functions: thinking, micro motor movements, macro motor movements, reading, and decision making. Each of these functions is characterized by performance and quality (where the quality is the deviation in performance from a target value of performance). For example, if the target value for reading is 100 words per minute (with 95% comprehension), then reading less than 65 words per minute (with 95% comprehension) is at the lower limit of performance while reading more than 300 words per minute (with 40% comprehension) is at the upper limit of performance. In other words, the quality of the reading skill is said to be low if the upper limit is not met or if the upper limit is exceeded with lower than expected comprehension.

A Figure of Merit (FoM) is the numerical value that represents a combination of measures of performance (or measures of effectiveness). From an equation (or relation) that relates key variables in a characteristically similar (or dissimilar way), can be identified as a FoM. In our case, the sensitivity of humans to sea sickness affects their performance (and quality of performance) on various functions. Violently ill people will be unable to perform the tasks of analytical thinking, micro motor movements, macro motor movements, reading, and decision making. Individuals who are weakly impacted by sea sickness will be able to perhaps stand (macro motor movements), but not think analytically. However, if individuals were weakly impacted, they may be able to think analytically, perform macro motor movements, and make decisions, but not read. Then the relation between the effects of sea sickness and the performance (and quality) of the functions associated with the jobs on a ship, are determined by the FoM of needing to perform analytical thinking (α), micro motor movements (β), macro motor movements (χ), reading (δ), and decision making (ε). Sea sickness contributes to lowering the performance of each of these functions. Therefore, a measure of sea sickness would be to measure the performance of individuals when they attempt to carry out each of the functions. The FoM for sea sickness on a ship is given by the multiplicative total of the self-assessment by individuals:

$$\text{FoM}(\gamma) = \alpha * \beta * \chi * \delta * \varepsilon$$

α and β and χ and δ and ε can occur simultaneously, but they are ordered by their thresholds of occurrence from most severe impact to least severe impact for each of the factors in γ. The smaller the FoM, the larger the effect of motion sickness on an individual's ability to perform the task being assessed. The inability to perform a task is related to the onset of causes leading directly to nausea, disorientation, or oculomotor effects.

- Analytical thinking (a): requires a distraction free environment
- Micro-motor movements (b): require ability to manipulate with digits (fingers and thumb) to perform tasks autonomically
- Macro-motor movements (c): require ability to remain standing in both a static and dynamic environment
- Reading (with comprehension) (d): requires a distraction free environment
- Decision making (including analytical thinking) (e):requires a distraction free environment

Motion sickness is a source of distraction; a confounding factor in micro-motor movements and macro-motor movements; a distractor for reading comprehension; and problematic for making decisions.

D. SEA MOTION EFFECTS

According to Coady (2010), Crossland, Colwell, Baitis, Holcombe, & Strong (1994) conducted research on human performance in moving environments to show direct and indirect effect upon individual's ability to perform a task. Coady stated that "Task performance can be affected by many factors such as loss of balance, sleep disruptions or poor quality of sleep and motion sickness" (Coady, 2010). In a review of motion sickness and biodynamic problems by Cheung, he categorized ship motion effects into three groups:

- Motion Sickness Incidence (MSI)
- Motion Induced Interruptions (MII)
- Motion Induced Fatigue (MIF)

Referenced by Coady (2010), the term MII describes events when an individual loses balance in a sea environment, thus removing a worker from the task at hand as he endeavors to recover his stability (Coady, 2010; Crossland & Rich, 2000). In summarizing Cheung's work, the MSI and MII will interfere with task performance due to sickness symptoms and the loss of balance. Coady (2010) stated that the final outcome of MSI is vomiting, and the event will likely to render the person incapacitated and to abandon one's duties. However, the complications associated with symptom severity of MSI are not well understood (Coady, 2010). In long duration tasks, the MIF caused by added muscular effort to maintain balance interferes with cognition or perception (Cheung, 2008), MIF has been attributed to loss of sleep due to motion or by increased energy expenditure due to the extra effort to maintain the body stability in a moving platform (Stevens & Parsons, 2002). In addition to signs and symptoms of motion sickness, the changes in behavior and performance includes: loss of well-being, distraction from task, decreased spontaneity, inactivity, being subdued, decreased readiness to perform, and decreased muscular and eye-hand coordination (Gillingham, 1966; Gordon, 1995; Guedry, 1978; Guedry, 1981; Kennedy, 1995; Lawson, 1998).

Referenced by Coady (2010), members of the American, British, Canadian and Dutch (ABCD) Working Group on Human Performance at Sea have contributed to a body of research that examines the influences of motion on physical and cognitive tasks. Figure 5 suggests that tasks performed in a moving environment can have both a direct and indirect effect on physical and cognitive tasks performed as part of regular command and control operations (Coady, 2010; Colwell, 2005).

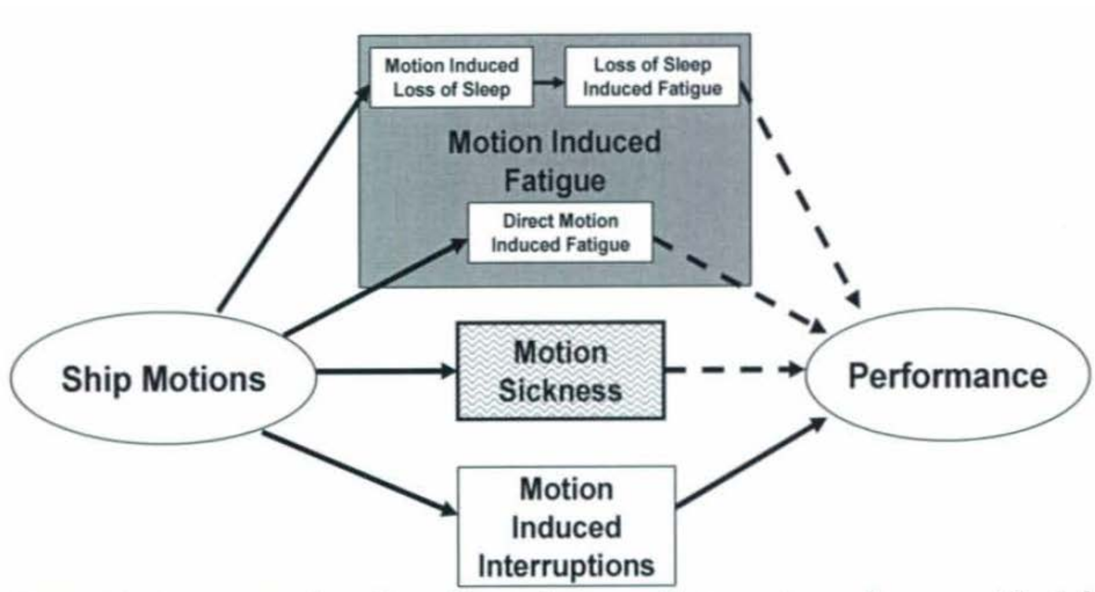

Figure 5. Motion effects on crew performance
(From Coady, 2010; After the ABCD Working Group)

According to Coady (2010), a 1997 NATO exercise collected data employing the NATO Performance Assessment Questionnaire (PAQ) from 1026 personnel from seven (NATO) ships and assessed the effects of motion sickness on several performance factors (Coady, 2010; Colwell, 2000). In the exercise, one-half of the participating subjects appealed mild to moderate motion sickness indications during the rough seas (Coady, 2010, Colwell, 2000). These same participants who experienced motion sickness symptoms also described substantially higher levels of difficulty in implementation of both cognitive and physical tasks (Coady 2010). Overall, researchers have found that self-reporting is highly correlative with appropriate symptoms and therefore taken to be a highly accurate form of gathering data for research.

The greatest impact of seasickness in the operational environment is maintaining the effective watchstanding. The ability of most vessels to carry out various mission related functions is degraded in severe weather conditions, primarily due to the adverse effects of ship motion on crew performance (Cheung, 2008). Cheung's observation from the crew's perspective, the loss of well-being interferes with the ability to perform task and can become a liability to others as well. He stated that "the sight and smell of vomitus in a confined space can affect morale and that seasickness, motion-induced fatigue and motion-induced interruptions are a potential problem for the safety and health of ship's crew at sea." (Cheung, 2008). It has been reported that severe seasickness erodes the will to survive and the affected individuals are less able and less willing to take positive action to aid survival (Cheung, 2008). A questionnaire-based survey (Cheung, 2002; Cheung, 2004) based on 2255 returned questionnaires revealed that the crew complained of a variety of problems including:

- Sleep disturbance;
- Task completion;
- Task performance;
- Loss-of-concentration;
- Decision-making; and
- Memory disorders.

Referenced by Cheung (2008), the correlation between sleep disturbance and ship motion was relatively high. Comparing the results with the findings by Colwell (2000), the NATO sea trial revealed consistency. The results suggested that significant correlation exist between fatigue and cognitive performance influenced by ship motion effects on sleeping and low level of motion sickness (Cheung, 2008). In general, it is apparent that the number of safety, health, and performance issues increases with the brutality of the weather conditions (Cheung).

E. PERFORMANCE QUALITY MODEL

The purpose of the watchstander performance quality analysis was to find the key source or critical watchstander position that may impact the overall ship's operational effectiveness or readiness. Additionally, with the use of FoM, the analysis can help to determine which of watchstander assignments are heavily loaded with performance qualities that may be affected by motion sickness. This correlation means that in the existence of moderate to severe motion sickness effects on the crew's performance, the correlative factors may be used to address and expose awareness to the command that more attention and consideration is required to ascertain the performance and readiness level of the watchstanders. The LCS platform has been selected for this analysis, since it is the primary ship being developed and procured in conjunction with the Navy's efforts to reduce manning requirements. The susceptibility of primary watchstanders onboard the LCS was examine with five essential performance quality that is affected by motion sickness. These performance qualities includes: making decisions, analytical thinking, reading, fine motor abilities, and gross motor abilities.

For every watchstander assignment, the five performance qualities should be observed to determine whether the performance and performance quality are reduced while taking into account that the individual on watchstation may be experiencing symptoms of slight to severe motion sickness. For example, in the scenario where the Officer of the Deck (OOD) is experiencing moderate to severe motion sickness, as many of the preview studies have shown, the individual will likely have impaired cognitive abilities that may affect and degrade the person's decision making performance or performance quality. Analytical task and reading ability will be also reduced due to the effects of motion sickness symptoms. The repetitive motions of the ship will increase the time it takes the individual to accomplish analytical and reading tasks. However, the effects of motion sickness on the crew may force some individuals to give up their task(s). The OOD does not require significant fine motor or gross motion performance quality, so it is accepted for the model that those two qualities are unaffected. All of the 36 critical watchstations were examined.

If the performance quality is affected for the watchstander, an "O" indicates that degradation of performance and readiness is present. In the case when the task does not have a performance or readiness impact due to motion sickness, an "X" indicates that no degradation to performance was applicable for that watchstation. Figure 6 shows the mapping of performance quality to the LCS primary watchstander assignment.

	ASSUMING MODERATE TO SEVERE MOTION SICKNESS						
		PERFORMANCE QUALITY					
#	**LCS PRIMARY WATCHSTANDER ASSIGNMENT**	MAKING DECISION	ANALYTICAL TASK	READING	FINE MOTOR	GROSS MOTION	FOM
1	OFFICER OF THE DECK UNDERWAY	0	0	0	X	X	3
2	JUNIOR OFFICER OF THE DECK	X	0	0	0	X	3
3	READINESS CONTROL OFFICER	X	0	0	X	X	2
4	ENGINEERING PLANT TECHNICIAN	X	X	0	0	0	3
5	TACTICAL ACTION OFFICER	0	0	0	0	X	4
6	FORCE NET SUPERVISOR (LCS-1)	X	0	0	X	X	2
7	TACTICAL AWARENESS COMMUNICATOR (LCS-2)	X	0	0	X	X	2
8	DEFENSE SYSTEMS OPERATOR (LCS-1)	X	0	0	X	X	2
9	COMBAT SYSTEMS MANAGER (LCS-2)	X	0	0	X	X	2
10	TOTAL SHIPS COMPUTING ENVIRONMENT OPERATOR	0	0	X	X	0	3
11	COMMUNICATIONS TECHNICIAN	X	X	0	X	0	2
12	AIR CONTROL TECHNICIAN	X	0	0	0	X	3
13	GUN FIRE CONTROL SYSTEM TECHNICIAN	X	X	0	0	X	2
14	57 MM GUN LOADER	X	0	X	0	0	3
15	CREW-SERVED WEAPONS GUNNER	0	0	X	0	0	4
16	DAMAGE CONTROL TEAM MEMBER	0	0	X	0	0	4
17	REPAIR LOCKER OFFICER	0	0	0	0	X	4
18	HELO CONTROL OFFICER	X	0	0	X	X	2
19	LANDING SIGNALMAN ENLISTED	X	0	X	X	0	2
20	CRASH AND SALVAGE TEAM	0	0	X	0	0	4
21	CHOCK & CHAIN OPERATOR	X	X	X	0	0	2
22	NAVIGATION EVALUATOR	0	0	0	X	X	3
23	LOOKOUT	X	0	X	X	0	2
24	CAPSTAN OPERATOR	X	X	X	X	0	1
25	LINE HANDLER	X	X	X	X	0	1
26	RIG CAPTAIN WINCH & CRANE OPERATOR	X	0	X	0	X	2
27	SLINDING PADEYE OPERATOR	X	0	X	0	X	2
28	DECK RIGGER	X	0	X	0	0	3
29	DECK SAFETY OFFICER	0	0	X	X	0	3
30	BOAT DAVIT CAPTAIN	0	0	X	X	0	3
31	BOAT DAVIT OPERATOR	X	X	X	0	X	1
32	BOAT COXSWAIN	X	0	X	0	X	2
33	BOAT ENGINEER	X	0	X	0	X	2
34	SEARCH & RESCUE SWIMMER	0	X	X	X	0	2
35	VBSS BOARDING OFFICER	0	0	X	0	0	4
36	VBSS BOARDING TEAM MEMBER	X	0	X	0	0	3

Figure 6. Mapping of performance quality to LCS primary watchstander assignments

FoM is determined by computing the number of the performance quality that was affected by the motion sickness. For example, the OOD has three performance qualities that were affected, making decisions, analytical tasks, and reading, which results to a FoM of three. The higher the value of FoM assigned to the watchstander assignment, the greater performance capacity required for that specific watchstation. For watchstation with FoM of four, more emphasis must be addressed to the individual's performance and readiness especially during the initial days of deployment which is likely to be affected by motion sickness (one to three days). The watchstanders highlighted are watchstations that have more than four performance quality affected from motion sickness symptoms. One obvious conclusion that can be made from analysis is that all watchstanders are affected by at least one performance quality.

For the primary watchstation onboard the LCS, a total of three watchstations have one reduced performance quality, 16 watchstations have a mixed combination of two reduced performance qualities, 11 watchstations have three reduced performance qualities, six watchstation with four performance qualities reduced, and finally no watchstations had motion sickness symptoms to degrade all of the performance qualities. The summary of FoM value with corresponding total number of watchstations is shown in Table 4.

Table 4. Summary of FoM for LCS watchstations

FOM	# of Watchstation
1	3
2	16
3	11
4	6
5	0

F. DATA COLLECTION

A descriptive study on incidence and severity of seasickness on sailors in the Bangladesh Navy was carried out from August 2007 to January 2009. The study included 1293 healthy male sailors, with ages ranging from 20 to 45 years old, over a total of 25 naval ships of medium to small size. The number of crew per ship ranged from 34 to 91. Each person traveled at sea in every season of the year, in both normal and inclement weather. Total sea trips for each ship were 8 to 14 per year. The number of days at sea ranged from 3 to 20. Sailors had variety of responsibilities and carried out their tasks in different positions aboard the ship. A written questionnaire was supplied to the medical assistant of the ships and information about physical and behavioral complaints of the sailors were collected (Malek, Maruf, & Hossain 2009). The results of the study included the sailor's demographics, duration at sea, types of symptoms, severity of seasickness, and sea state conditions.

Table 5. Characteristics of sailors (From Malek, Maruf, & Hossain, 2009)

Parameters	Values (mean ± SD)
Age(years)	30 ± 8.78
Body weight(Kg)	58.7 ± 5.69
Height(cm)	171 ± 4.26

Table 5 indicates the parameters of the population of sailors who participated in the Bangladesh Navy study. The mean age was 30 years with a standard deviation (SD) of 8.78years. The mean body weight of the sailors was 58.7 kg with an SD of 5.69kg. The mean height of 1293 sailors was 171 cm with an SD of 4.26cm.

Table 6. Types of symptoms observed from total of 1293 healthy sailors (After Malek, Maruf, & Hossain, 2009)

Symptoms	Number	Percent
Dizziness	96	18.32%
Fatigue	89	17.09%
Vertigo	59	11.36%
Epigastric discomfort	51	9.74%
Nausea	91	17.40%
Vomiting	34	6.57%

Table 6 breaks down the sailor reports of motion sickness into six categories of symptoms. The different types of symptoms of seasickness experienced by sailors involve dizziness, fatigue, vertigo, epigastric discomfort, nausea, and vomiting. A total of 523 out of 1293 sailors experienced some type of motion sickness symptoms during the period of data collection (Malek, Maruf, & Hossain 2009).

Table 7. Severity of seasickness on 523 affected sailors (From Malek, Maruf, & Hossain, 2009)

Severity of seasickness	Number	Percentage
Minor inconvenience, self limitingand not required rest	412	78.78%
Require rest for 24 hours	101	19.31%
Complete excuse of duty throughout sea period	10	1.91%
Total affected sailors	523	100%

The majority of the motion sick sailors developed minor inconveniences that were self-limiting, but did not require rest or requests to be excused from duty for greater than 24 hours. Only ten cases required excused permission from duty for the entire sea period (Malek, Maruf, Hossain, 2009) of that voyage. Severity of seasickness is shown in Table 7.

Table 8. Incidence of seasickness in relation to sea condition (From Malek, Maruf, & Hossain, 2009)

Sea condition	Number	Percentage
Calm	20	3.82%
Moderate	127	24.28%
Rough	375	71.70%

Finally, the incidence of seasickness in relation to sea condition is shown in Table 8. The sea condition was divided into three various conditions of calm, moderate, and rough. Out of the total 523 sailors affected by motion sickness, 20 sailors were affected during calm sea condition, 127 showed symptoms during moderate sea condition, and the remainder of 375 sailors showed severe signs of motion sickness at rough sea. The data collected among naval personnel of Khulna Naval Base shows compatibility with the LCS platform. As discussed early, the objective/threshold of work force for the LCS platform is 50, which puts the LCS in the similar categories as the naval ships used in this study. The incidence of seasickness in relation to sea condition is integrated further with the mapping of performance quality to the LCS primary watchstander assignment in order to determine the degradation of watchstanders operational effectiveness.

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IV. RESULTS/DISCUSSION

A. OPERATIONAL READINESS AND PERFORMANCE

The purpose of integrating the data collected by Malek, Maruf, & Hossain (2009) with the performance quality model developed for this thesis was to add the variability of the sea state into the model of impacts on the execution of the LCS manning proficiency. The final model of manning proficiency was constructed to predict and estimate the degradation of operational effectiveness of the watchstanders due to the motion sickness symptoms.

At this early stage of the model building, the assumption was made that the degradation of any performance qualities would affect the watchstanders operational effectiveness equally. For example, it was efficient to assume that reduced gross motion during firefighting probably would have larger impact on operational effectiveness than that of an engineering plant technician having a reduced ability to read the emergency operating procedures. However, due to the complexity of determining the exact impact of performance quality on the operational effectiveness, the assumption was made that any degraded performance quality would also equally affect operational effectiveness.

Of the 36 watchstanders onboard the LCS, performance quality was affected by motion sickness symptoms on 12 watchstanders in making decisions, 28 watchstanders degraded in analytical tasks, 15 watchstanders in reduced reading capability, 19 watchstanders in fine motor skills, and 18 watchstanders in gross motion skills. Summing up the degraded performance qualities in all watchstations, a total of 92 were affected on the ship. Table 9 summarizes the total number of performance qualities affected in 36 watchstander assignments due to motion sickness symptoms.

Table 9. Performance qualities affected in 36 watchstanders

PERFORMANCE QUALITY	# of PQ affected
MAKING DECISION	12
ANALYTICAL TASK	28
READING	15
FINE MOTOR	19
GROSS MOTION	18
TOTAL	92

The operational effectiveness of the watchstanders was determined using the total of 92 performance qualities affected by motion sickness symptoms. An assumption was made that if there was no motion or motion sickness involved, the 92 performance qualities would not be affected, leaving operational effectiveness of the watchstanders at 100%. In other words, we assumed there are a total of 92 performance qualities that make up the total operational effectiveness of the watchstanders.

In order to determine the expected degradation of watchstander performance quality during calm seas, the following calculations were carried out. First, the total number of performance qualities affected in making decisions was multiplied by 3.82%, which was the expected number of people to be affected by motion sickness in calm seas. Next the total number of performance qualities affected by analytical task was also multiplied by 3.82%. The performance qualities of reading, fine motor ability, and gross motion ability also were multiplied. The calculated value was the affected value and reduced the number of performance qualities based on the sea conditions. In a calm sea, the watchstanders were affected or reduced in 3.5 performance qualities out of 92 total performance qualities of ships watchstanders. In a moderate sea, the watchstanders affected or reduced in 22.3 out of 92 performance qualities. In a heavy sea, the number of watchstanders affected or reduced extremely increased to 65.9 out of 92 performance qualities. In order to determine the operational effectiveness of watchstanders, the total number of performance qualities of the ship was subtracted by the total reduced performance qualities based on various sea states. Then this number was divided by the total number of performance qualities of all watchstanders to find the percent degradation of performance qualities in various sea conditions. The result shows that the operational effectiveness in calm seas was 96.18%; in moderate seas, 75.72%; and in heavy seas 28.30%.

Table 10. Operational effectiveness of watchstander performance quality model

		P&R affected % based on Sea Condition		
		Calm Sea	Moderate Sea	Heavy Sea
PERFORMANCE QUALITY	**# of PQ affected**	3.82%	24.28%	71.70%
MAKING DECISION	12	0.4584	2.9136	8.604
ANALYTICAL TASK	28	1.0696	6.7984	20.076
READING	15	0.573	3.642	10.755
FINE MOTOR	19	0.7258	4.6132	13.623
GROSS MOTION	18	0.6876	4.3704	12.906
TOTAL	92	3.5144	22.3376	65.964
OPERATIONAL EFFECTIVENESS		**96.18%**	**75.72%**	**28.30%**

Table 10 shows the integrated operational effectiveness of the watchstander performance quality model. The incidence of seasickness in relation to sea condition was integrated into the performance quality model. Using the data provided from the Bangladesh Navy study (Malek, Maruf, & Hossain, 2009), 3.82% of the people showed signs of motion sickness symptoms during the calm sea condition, 24.28% during the moderate sea condition, and 71.70% during the heavy sea condition.

The predicted operational effectiveness using the model does not determine a specific effectiveness, such as combat effectiveness, as there are other factors which ameliorate highly focused intentions for survival. The primary intent of the model was to show the expected degradation of the total performance quality of the watchstanders based on the various sea conditions. Motion sickness effects on the crew increase with the rise in the sea state conditions.

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V. CONCLUSION AND RECOMMENDATIONS

A. SUMMARY AND CONCLUSIONS

The literature review covered many aspects of motion sickness and the possible motion sickness symptoms that affect crew readiness and performance. Primary watchstanders performance is critical to future design ships as these newer ships will advance further in technology and eventually will replace and supplement more of the human element. After reviewing and analyzing the effects of motion sickness on human performance, the objective was to find data that can be used to integrate into a working model to estimate the expected and reduced crew performance quality.

The goal of this thesis was to expand the knowledge of motion sickness symptom threats and impacts on operational effectiveness of watchstanders at early stage of the deployment where crews are more susceptible to sea environment. Considering previous research and the integration of collected data with developed performance quality model, it appears there is a degradation of watchstanders performance quality in even low sea state environments. The integrated performance quality model also indicates that the operational effectiveness of watchstanders performance onboard ships will decrease with the increased severity of sea state conditions.

It is important that commanders and higher ranking officials be made aware of this matter for better strategic planning of an operation. Especially during crisis situation when ships are deployed rapidly, the higher authorities should be aware that crew readiness and performance levels are degraded due to motion sickness effects at early stage of deployment (one to three days). It is also suggested that depending on the sea state condition of the transit, the operational effectiveness of watchstanders aboard ships should be expected to be degraded gradually, and show marked decrease in effectiveness with higher severity of sea state conditions. This thesis highly recommends that motion sickness effects on crew performance be taken into account when reporting operational readiness and performance level of the ships.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

There is a need for future research in this area to ensure the performance quality model can further help in estimating the expected and reduced crew performance during the initial stage of the deployment (one to three days). The long term monitoring and gathering data of motion sickness onboard the LCS is recommended. Especially during the first couple days of operation in an at sea environment, it is recommended to collect data on motion sickness effects on the crew by observation and questionnaires. Questionnaires should be completed by all critical watchstanders. With the collection of data, a better knowledge base on degradation of performance quality on watchstanders can be investigated for effects of hull design, equipment placement, and compartment size, wall color, ceiling height, ergonomic design of chairs, and preparatory training to maintain “sea legs.” The analysis of the data can further improve the knowledge of motion sickness impact on the crew during the early stage of the deployment onboard the LCS.

It is highly recommended to engage a future researcher in the issues of interoperability as measured by the performance quality model using actual data collected from the LCS.

APPENDIX A. DOUGLAS SEA SCALE

Degree	Height (m)	Description
0	no wave	Calm (Glassy)
1	0 - 0.10	Calm (Rippled)
2	0.10 - 0.50	Smooth
3	0.50 - 1.25	Slight
4	1.25 - 2.50	Moderate
5	2.50 - 4.00	Rough
6	4.00 - 6.00	Very Rough
7	6.00 - 9.00	High
8	9.00 - 14.00	Very High
9	14.00+	Phenomenal

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APPENDIX B. LIST OF US NAVY SHIP AND HOMEPORT

Bangor, WA

USS Alabama	SSBN 731
USS Connecticut	SSN 22
USS Henry M. Jackson	SSBN 730
USS Jimmy Carter	SSN 23
USS Kentucky	SSBN 737
USS Louisiana	SSBN 743
USS Maine	SSBN 741
USS Michigan	SSGN 727
USS Nebraska	SSBN 739
USS Nevada	SSBN 733
USS Ohio	SSGN 726
USS Pennsylvania	SSBN 735
USS Seawolf	SSN 21

Bremerton, WA

USS John C. Stennis	CVN 74

Everett, WA

USS Ford	FFG 54
USS Ingraham	FFG 61
USS Momsen	DDG 92
USS Nimitz	CVN 68
USS Rodney M. Davis	FFG 60
USS Shoup	DDG 86

Gaeta, Italy

USS Mount Whitney	LCC 20

Groton, CT

USS Alexandria	SSN 757
USS California	SSN 781
USS Dallas	SSN 700
USS Hartford	SSN 768

USS Miami	SSN 755
USS Mississippi	SSN 782
USS Missouri	SSN 780
USS New Hampshire	SSN 778
USS New Mexico	SSN 779
USS Pittsburgh	SSN 720
USS Providence	SSN 719
USS Springfield	SSN 761
USS Toledo	SSN 769

Guam

USS Buffalo	SSN 715
USS Frank Cable	AS 40
USS Houston	SSN 713
USS Oklahoma City	SSN 723

Kings Bay, GA

USS Alaska	SSBN 732
USS Florida	SSGN 728
USS Georgia	SSGN 729
USS Maryland	SSBN 738
USS Rhode Island	SSBN 740
USS Tennessee	SSBN 734
USS Wyoming	SSBN 742

Little Creek, VA

USS Ashland	LSD 48
USS Carter Hall	LSD 50
USS Fort McHenry	LSD 43
USS Gunston Hall	LSD 44
USS Hurricane	PC 3
USS Oak Hill	LSD 51
USS Squall	PC 7
USS Thunderbolt	PC 12
USS Whidbey Island	LSD 41
USS Monsoon	PC 4
USS Shamal	PC 13
USS Tempest	PC 2
USS Tornado	PC 14

USS Zephyr	PC 8

Manama, Bahrain

USS Ardent	MCM 12
USS Chinook	PC 9
USS Dextrous	MCM 13
USS Firebolt	PC 10
USS Gladiator	MCM 11
USS Scout	MCM 8
USS Sirocco	PC 6
USS Typhoon	PC 5
USS Whirlwind	PC 11

Mayport, FL

USS Carney	DDG 64
USS De Wert	FFG 45
USS Farragut	DDG 99
USS Gettysburg	CG 64
USS Halyburton	FFG 40
USS Hue City	CG 66
USS Klakring	FFG 42
USS Philippine Sea	CG 58
USS Robert G. Bradley	FFG 49
USS Roosevelt	DDG 80
USS Samuel B. Roberts	FFG 58
USS Simpson	FFG 56
USS Taylor	FFG 50
USS The Sullivans	DDG 68
USS Underwood	FFG 36
USS Vicksburg	CG 69

Norfolk, VA

USS Abraham Lincoln	CVN 72
USS Albany	SSN 753
USS Anzio	CG 68
USS Arleigh Burke	DDG 51
USS Bainbridge	DDG 96
USS Barry	DDG 52
USS Bataan	LHD 5

USS Boise	SSN 764
USS Bulkeley	DDG 84
USS Carr	FFG 52
USS Cole	DDG 67
USS Donald Cook	DDG 75
USS Dwight D. Eisenhower	CVN 69
USS Elrod	FFG 55
USS Enterprise	CVN 65
USS Forrest Sherman	DDG 98
USS George H.W. Bush	CVN 77
USS Gonzalez	DDG 66
USS Gravely	DDG 107
USS Harry S. Truman	CVN 75
USS Iwo Jima	LHD 7
USS James E Williams	DDG 95
USS Jason Dunham	DDG 109
USS Kauffman	FFG 59
USS Kearsarge	LHD 3
USS Laboon	DDG 58
USS Leyte Gulf	CG 55
USS Mahan	DDG 72
USS Mason	DDG 87
USS McFaul	DDG 74
USS Mesa Verde	LPD 19
USS Mitscher	DDG 57
USS Monterey	CG 61
USS Montpelier	SSN 765
USS Nassau	LHA 4
USS New York	LPD 21
USS Newport News	SSN 750
USS Nicholas	FFG 47
USS Nitze	DDG 94
USS Norfolk	SSN 714
USS Normandy	CG 60
USS Oscar Austin	DDG 79
USS Porter	DDG 78
USS Ramage	DDG 61
USS Ross	DDG 71
USS San Antonio	LPD 17
USS San Jacinto	CG 56
USS Scranton	SSN 756

USS Stout	DDG 55
USS Theodore Roosevelt	CVN 71
USS Truxtun	DDG 103
USS Vella Gulf	CG 72
USS Wasp	LHD 1
USS Winston S Churchill	DDG 81

Norfolk, Va.

USS Arlington	LPD 24

Pearl Harbor, HI

USS Bremerton	SSN 698
USS Chafee	DDG 90
USS Charlotte	SSN 766
USS Cheyenne	SSN 773
USS Chicago	SSN 721
USS Chosin	CG 65
USS Chung-Hoon	DDG 93
USS City of Corpus Christi	SSN 705
USS Columbia	SSN 771
USS Columbus	SSN 762
USS Crommelin	FFG 37
USS Greeneville	SSN 772
USS Hawaii	SSN 776
USS Hopper	DDG 70
USS Jacksonville	SSN 699
USS Key West	SSN 722
USS La Jolla	SSN 701
USS Lake Erie	CG 70
USS Louisville	SSN 724
USS Michael Murphy	DDG 112
USS North Carolina	SSN 777
USS O'kane	DDG 77
USS Olympia	SSN 717
USS Paul Hamilton	DDG 60
USS Port Royal	CG 73
USS Reuben James	FFG 57

USS Russell	DDG 59
USS Santa Fe	SSN 763
USS Texas	SSN 775
USS Tucson	SSN 770

Portsmouth, NH

USS Annapolis	SSN 760
USS Helena	SSN 725
USS Pasadena	SSN 752
USS San Juan	SSN 751
USS Virginia	SSN 774

Portsmouth, VA

USS West Virginia	SSBN 736

San Diego

USS Anchorage	LPD 23

San Diego, CA

PCU Coronado	LCS 4
USS Albuquerque	SSN 706
USS Antietam	CG 54
USS Asheville	SSN 758
USS Benfold	DDG 65
USS Bonhomme Richard	LHD 6
USS Boxer	LHD 4
USS Bunker Hill	CG 52
USS Cape St. George	CG 71
USS Carl Vinson	CVN 70
USS Champion	MCM 4
USS Chancellorsville	CG 62
USS Chief	MCM 14
USS Cleveland	LPD 7
USS Comstock	LSD 45
USS Curts	FFG 38
USS Decatur	DDG 73
USS Devastator	MCM 6

USS Dubuque	LPD 8
USS Fort Worth	LCS 3
USS Freedom	LCS 1
USS Gary	FFG 51
USS Green Bay	LPD 20
USS Gridley	DDG 101
USS Halsey	DDG 97
USS Hampton	SSN 767
USS Harpers Ferry	LSD 49
USS Higgins	DDG 76
USS Howard	DDG 83
USS Independence	LCS 2
USS Jefferson City	SSN 759
USS John Paul Jones	DDG 53
USS Kidd	DDG 100
USS Lake Champlain	CG 57
USS Makin Island	LHD 8
USS McClusky	FFG 41
USS Milius	DDG 69
USS Mobile Bay	CG 53
USS New Orleans	LPD 18
USS Pearl Harbor	LSD 52
USS Peleliu	LHA 5
USS Pinckney	DDG 91
USS Pioneer	MCM 9
USS Preble	DDG 88
USS Princeton	CG 59
USS Rentz	FFG 46
USS Ronald Reagan	CVN 76
USS Rushmore	LSD 47
USS Sampson	DDG 102
USS San Diego	LPD 22
USS San Francisco	SSN 711
USS Sentry	MCM 3
USS Spruance	DDG 111
USS Sterett	DDG 104
USS Stockdale	DDG 106
USS Thach	FFG 43
USS Topeka	SSN 754
USS Vandegrift	FFG 48
USS Warrior	MCM 10
USS Wayne E. Meyer	DDG 108

USS William P. Lawrence	DDG 110

Sasebo, Japan

USS Avenger	MCM 1
USS Defender	MCM 2
USS Denver	LPD 9
USS Essex	LHD 2
USS Germantown	LSD 42
USS Guardian	MCM 5
USS Patriot	MCM 7
USS Tortuga	LSD 46

Yokosuka, Japan

USS Blue Ridge	LCC 19
USS Cowpens	CG 63
USS Curtis Wilbur	DDG 54
USS Fitzgerald	DDG 62
USS George Washington	CVN 73
USS John S McCain	DDG 56
USS Lassen	DDG 82
USS McCampbell	DDG 85
USS Mustin	DDG 89
USS Shiloh	CG 67
USS Stethem	DDG 63

APPENDIX C. DISTANCE TRAVEL BASED ON SPEED AND NUMBER OF DAYS

	Distance traveled based on # of days (in Nautical miles)				
Travel Speed (in knots)	**1**	**2**	**3**	**4**	**5**
1	24	48	72	96	120
2	48	96	144	192	240
3	72	144	216	288	360
4	96	192	288	384	480
5	120	240	360	480	600
6	144	288	432	576	720
7	168	336	504	672	840
8	192	384	576	768	960
9	216	432	648	864	1080
10	240	480	720	960	1200
11	264	528	792	1056	1320
12	288	576	864	1152	1440
13	312	624	936	1248	1560
14	336	672	1008	1344	1680
15	360	720	1080	1440	1800
16	384	768	1152	1536	1920
17	408	816	1224	1632	2040
18	432	864	1296	1728	2160
19	456	912	1368	1824	2280
20	480	960	1440	1920	2400
21	504	1008	1512	2016	2520
22	528	1056	1584	2112	2640
23	552	1104	1656	2208	2760
24	576	1152	1728	2304	2880
25	600	1200	1800	2400	3000
26	624	1248	1872	2496	3120
27	648	1296	1944	2592	3240
28	672	1344	2016	2688	3360
29	696	1392	2088	2784	3480
30	720	1440	2160	2880	3600

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APPENDIX D. LCS PRIMARY WATCHSTANDER ASSIGNMENT

P	PRIMARY WATCHSTANDER ASSIGNMENT	
A	ALTERNATE WATCHSTANDER	Added to provide CO watchbill flexibility
OOD	OFFICER OF THE DECK UNDERWAY	Unique to LCS Class ships
JOD	JUNIOR OFFICER OF THE DECK	Unique to LCS Class ships
RCO	READINESS CONTROL OFFICER	
EPT	ENGINEERING PLANT TECHNICIAN	
TAO	TACTICAL ACTION OFFICER	
FNS	FORCE NET SUPERVISOR	LCS-1 Class only
TAC	TACTICAL AWARENESS COMMUNICATOR	LCS-2 Class only
DSO	DEFENSE SYSTEMS OPERATOR	LCS-1 Class only
CSM	COMBAT SYSTEMS MANAGER	LCS-2 Class only
TSC	TOTAL SHIPS COMPUTING ENVIRONMENT OPERATOR	
COM	COMMUNICATIONS TECHNICIAN	
ACT	AIR CONTROL TECHNICIAN	Also known as ASTAC
GFC	GUN FIRE CONTROL SYSTEM TECHNICIAN	
57M	57 MM GUN LOADER	
CSW	CREW-SERVED WEAPONS GUNNER	Includes 25mm, .50cal, Shotgun, M16, and M9
DC	DAMAGE CONTROL TEAM MEMBER	Includes all positions from Utilityman to On-Scene Leader (313 qualified)
RLO	REPAIR LOCKER OFFICER	Includes all RLOs (IET and DCRS) and DCA (when assigned)
HCO	HELO CONTROL OFFICER	
LSE	LANDING SIGNALMAN ENLISTED	Includes all CST requirements
CST	CRASH AND SALVAGE TEAM	
CCO	CHOCK & CHAIN OPERATOR	Includes all CST requirements
NAV	NAVIGATION EVALUATOR	Executive Officer will usually be on the bridge for Cond II Nav situations
LKO	LOOKOUT	Includes Low Visibility detail Lookouts
CAP	CAPSTAN OPERATOR	Includes Anchoring and Mooring Evolutions
LHR	LINE HANDLER	Includes all Line Handling evolutions (Mooring, RAS, Launch & Recovery)
RCN	RIG CAPTAIN	
WOR	WINCH & CRANE OPERATOR	Includes Launch & Recovery and TRIGON
SPO	SLIDING PADEYE OPERATOR	
DKR	DECK RIGGER	
SAF	DECK SAFETY OFFICER	
BDC	BOAT DAVIT CAPTAIN	
BDO	BOAT DAVIT OPERATOR	
BCX	BOAT COXSWAIN	
BEN	BOAT ENGINEER	
SAR	SEARCH & RESCUE SWIMMER	
VBO	VBSS BOARDING OFFICER	
VBS	VBSS BOARDING TEAM MEMBER	
CDO	COMMNAD DUTY OFFICER	
OODi	OFFICER OF THE DECK INPORT	
POW	PETTY OFFICER OF THE WATCH	
CSW	CREW-SERVED WEAPONS GUNNER	Includes 25mm, .50cal, Shotgun, M16, and M9
GUN	ATFP GUN OPERATOR	Includes Shotgun, M16, and M9 (Rovers & Sentries)
EDO	ENGINEERING DUTY OFFICER	(RCO Qualified)
EPT	ENGINEERING PLANT TECHNICIAN	
RLO	IET REPAIR LOCKER OFFICER	
DC	DAMAGE CONTROL TEAM MEMBER	Includes all positions from Utilityman to On-Scene Leader (313 qualified)

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